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THE COAL OUTPUT RESERVE IN A GROUP OF COLLIERIES

Abstract. In the paper the author discussed issues concerning a coal output reserve in a group of collieries. The maximization of a coal output in a group of collieries determines the highest possible work productivity, which is one of key indicators affecting the economic efficacy in hard coal mining activity. The author focused on factors determining shearer's productivity and its effective work time in a longwall. Technical and organisational determinants of work performance are taken into consideration to analyse technical and organisational solutions which make technological processes less labour-consuming. Additionally, the algorithm of the determination of potential coal output reserve in a group of longwalls was presented. The research analysis was focused on a selected group of longwalls of two collieries. The necessary input data derive from source materials of collieries and monitoring of longwalls' work parameters. The undertaken study brought in the estimated changes of work performance in a selected group of collieries.

Keywords: coal output reserve, work performance, a group of collieries

REZERWA WYDOBYCIA WĘGLA W GRUPIE KOPALŃ WĘGLA KAMIENNEGO

Streszczenie. W artykule autor podjął dyskusję dotyczącą rezerwy wydobycia dobowego węgla w grupie kopalń węgla kamiennego. Maksymalizacja wydobycia dobowego węgla kamiennego w grupie kopalń determinuje najwyższy możliwy do osiągnięcia poziom wydajności pracy, która jest jednym z kluczowych wskaźników decydujących o efektywności ekonomicznej w działalności górnictwa węgla kamiennego. Autor skoncentrował swoje badania na czynnikach decydujących o produktywności kombajnu ścianowego oraz efektywnym czasie jego pracy w ścianie wydobywczej. Techniczne i organizacyjne determinanty wydajności pracy zostały poddane analizie w celu ustalenia rozwiązań techniczno-

-organizacyjnych umożliwiających ograniczenie pracochłonności procesów technologicznych. Dodatkowo w artykule został przedstawiony algorytm ustalenia potencjalnej rezerwy wydobycia dobowego w grupie ścian wydobywczych. Obliczenia przeprowadzono dla grupy ścian wydobywczych w dwóch kopalniach węgla kamiennego. Niezbędne do analizy dane wejściowe zostały uzyskane z materiałów źródłowych kopalń oraz monitoringu parametrów pracy ścian wydobywczych. Podjęte badania umożliwiły oszacowanie zmian wydajności pracy w wyselekcjonowanej grupie kopalń.

Słowa kluczowe: rezerwa wydobycia dobowego, wydajność pracy, grupa kopalń węgla kamiennego

1. Introduction

Hard coal mining in Poland has been radically restructured since 1989. All changes in key activity areas concerning technical and technological, human resources, and financial and organisational restructuring were mainly aimed at a better adaptation to changing internal and external conditions of a coal sector. The most important aspect in mining activity was, and still is further reducing a unit production cost and increasing work performance which affect coal companies' economic indicators[1].

At present, actions undertaken in the Polish hard coal mining sector in organizational, structural, technical and technological changes are aimed at achieving the planned coal production within a limited number of coalmines and longwalls. The production concentration requires the maximum use of the productivity of machinery and equipment and collieries' infrastructure. Reducing a number of active coalmines and thus productive longwalls can, on one hand, bring economic benefits, but on the other hand leads to increased risks for stable coal production. Therefore, it is so important to undertake in-depth analyses of organizational, technical and technological possibilities for achieving a planned level of coal production for a group of collieries operating within a single coal company.

The production potential of a group of collieries depends on mining and geological conditions and applied technical and organizational solutions. Coalmine's underground and surface infrastructure, installed machinery and equipment, the appropriate selection of

[1] Klank M.: The determinants in the development of coal mining sector productivity. "Archives of Mining Sciences", Vol. 56, No. 3, 2011, p. 507; Simões J.M., Gomes C.F., Yasin M.M.: A literature review of maintenance performance measurement: A conceptual framework and directions for future research. "Journal of Quality in Maintenance Engineering", No. 2, 2011, p. 116; Armstrong M.: Zarządzanie zasobami ludzkimi. Oficyna Wolters Kluwer Business, Kraków 2007; Jonek-Kowalska I.: Challenges for long-term industry restructuring in the Upper Silesian Coal Basin: What has Polish coal mining achieved and failed from a twenty-year perspective? "Resources Policy", Vol. 44, 2015, p. 135; Bijańska J.: Prognozowanie kształtowania się rentowności produkcji w kopalniach węgla kamiennego w latach 2010-2020. Wydawnictwo Politechniki Śląskiej, Gliwice 2011.

employees in terms of the number and necessary competences and skills are factors that determine effective, stable and safe realisation of a production process. Coal production, including extraction, transportation and processing, requires many technological processes[2] that are characterized by specific labour-consumption, which determines the productivity of colliery's technical system.

From the point of view of maximizing labour productivity in a colliery, it is important both to maximize the use of production potential and to optimize human resources in terms of an appropriate quantitative and qualitative structure for effective realisation of technological processes. Labour productivity is crucial considering the criterion of maximizing economic efficiency indicators of a colliery or a coal company.

The important issue for improving work performance and economic indicators in coal companies is the optimal level and structure of employment and effective work time management of employed miners, including external firms[3]. Effective work time and labour consumption determine the level and structure of employment in a colliery[4].

In the article the author presented the results of the study concerning the issue of a coal output reserve and its influence on the maximum possible work performance in a group of collieries. Key factors determining work performance were discussed and were taken into the analysis of changes resulting in increasing work productivity indicators.

The maximization of a coal output in a group of collieries determines the highest possible work productivity, which is one of key indicators affecting the economic efficacy in hard coal mining activity. The author focused on factors determining shearer's productivity and its effective work time in a longwall. Technical and organisational determinants of work performance are taken into consideration to analyse technical and organisational solutions which make technological processes less labour-consuming. Additionally, the algorithm of a coal output allocation in a group of longwalls was presented to achieve the highest possible work performance. The research analysis was focused on a selected group of longwalls of two

[2] Gumiński A.: Analiza pracochłonności procesów technologicznych realizowanych w ścianie wydobywczej w kopalni węgla kamiennego, [w:] Karbownik A. (red.): Czynniki kształtujące elementy systemu zarządzania współczesną organizacją. Wydawnictwo Politechniki Śląskiej, Gliwice 2008, s. 81; Gumiński A.: Czynniki decydujące o wydajności pracy w wybranych kopalniach węgla kamiennego. „Wiadomości Górnicze", t. 63, nr 10, 2012, s. 562.

[3] Karbownik A., Gumiński A.: Zakres i skala procesów technologicznych realizowanych przez firmy zewnętrzne w kopalniach węgla kamiennego. „Przegląd Górniczy", nr 9, 2011, s. 65; Gumiński A.: Czynniki obniżające efektywny czas pracy zatrudnionych w kopalni węgla kamiennego. Zeszyty Naukowe Politechniki Śląskiej, s. Organizacja i Zarządzanie, z. 56, Gliwice 2011, s. 89.

[4] Jonek-Kowalska I.: The effects of evolutionary employment restructuring in the Polish mining enterprises in the context of sector risk. "International Journal of Contemporary Management.", Vol. 13, No. 4, 2014, p. 21; Gumiński A.: The influence of effective work time on an employment level in a colliery – case study. Zeszyty Naukowe Politechniki Śląskiej, s. Organizacja i Zarządzanie, z. 91, 2016, s. 111; Gumiński A.: Model

collieries. The necessary input data derive from source materials of collieries and monitoring of longwalls' work parameters. The undertaken study brought in the estimated changes of work performance in a selected group of collieries.

2. Factors determining work productivity in a group of collieries

For a further analysis, a gross productivity indicator was selected that can be given for a colliery or a group of collieries in the form of a following formula:

$$W = \frac{P_b}{Z} \tag{1}$$

where:

P_b – average annual gross coal production [Mg/r],

Z – average employment level in a colliery/ a group of collieries [empl.].

Therefore, the way to higher productivity in a group of collieries should be focused on maximizing coal production, which is related to increasing the productivity of machinery[5] and the best possible adjustment of an employment level for stable and efficient realisation of technological processes. In coal mines, geological conditions of coal beds and existing natural hazards determine applied technical and organizational solutions. Adequately selected technical equipment, mechanization and automation of technological processes, proper work organization and the selection of employees with appropriate competences and skills can significantly increase the level of gross productivity indicator.

In general, main factors and determinants that affect the level of total gross productivity indicator in a group of collieries are:

- geological and mining conditions,
- natural hazards,
- employment level and structure in analysed collieries,
- effective work time of miners,
- production process organisation (extraction, transportation and coal processing),
- underground transportation infrastructure,
- colliery's shafts infrastructure,

planowania poziomu zatrudnienia w kopalni węgla kamiennego i w grupie kopalń. Wydawnictwo Politechniki Śląskiej, Gliwice 2010.

[5] Relkar A.S., Nandurkar K.N.: Optimizing & Analysing Overall equipment efficiency. (OEE) through Design of Experiments. „Procedia Engineering", Vol. 38, 2012, p. 2973.

- the infrastructure of a coal processing plant,
- the range and scale of machinery breakdowns,
- the level and structure of coal production,
- labour consuming of technological processes,
- competences and skills of employees,
- applied technical and technological solutions.

3. The analysis of a coal output reserve and its influence on work productivity in a selected group of longwalls

In the range of undertaken study the following issues were analysed:

- the choice of a group of longwalls for the analysis,
- the determination of geological and mining conditions based on technical documentation,
- the determination of technical and organizational parameters characterizing analysed longwalls based on monitoring of their work,
- the determination of possible changes in key parameters affecting higher efficient daily work time of a longwall shearer, and as a results higher daily coal output,
- the determination of a daily output reserve for each of the analysed longwalls and totally for a group of longwalls in calculation variants,
- the determination of changes of an employment level in a group of productive workers and non-productive workers in an analysed group of collieries,
- the determination of total gross productivity indicator for an analysed group of collieries in calculation variants,
- the proposal of actions enabling the increase of effective longwall shearer's work time in analysed collieries.

The preliminary stage of the study involved identifying coal mines and longwalls selected for a further analysis. Two collieries were selected, where coal production was conducted totally in 7 longwalls. Basic geological and mining parameters of analysed longwalls were given in table 1.

Table 1

Geological and mining parameters of analysed longwalls

Id.	Parameter	Unit	The name of a longwall						
			Longwall A	Longwall B	Longwall C	Longwall D	Longwall E	Longwall F	Longwall G
1.	Coal deposit		205/1	209	209	209	209	206/1	206/1
2.	Methane hazard category		-	-	-	-	-	-	-
3.	Water hazard category		I	I	I	I	I	I	I
4.	Rockburst hazard category		-	I	I	I	I	-	-
5.	Longwall's length	[m]	225,00	230,99	184,92	146,25	169,00	195,00	110,00
6.	Longwall's height	[m]	1,73	2,20	2,62	3,57	4,40	2,10	2,10
7.	Longwall's run	[m]	403 / 1056	1094 / 2184	486,0	281,0	1 995,0	1 485,0	525,0
8.	Longwall's longitudinal slope	[°]	1-3	1-3	0-2	2-5	0-7	1÷8	0-9
9.	Longwall's transverse slope	[°]	3-5	2-5	2-6	0-1	-4,5 +8,5	1÷6	1 ÷ 6,8
10.	Daily longwall advancement	[m/d]	4,43	4,22	4,30	3,90	6,34	2,90	1,60
11.	Longwall's exploitation time	[mies.]	4,4	12,4	5,4	3,6	12,0	15,0	5,0
12.	Shearer's type		KGE-710FM	KGE-710FM	KSW-880EU/1k	KSW-2000E1	KSW-1500 EU	FS 400/1.0	KSW 880 EU
13.	Longwall conveyor's type		Rybnik-850	Glinik 298/800	Rybnik-850	Rybnik-1100	Rybnik 1100	RYBNIK-850	GLINIK-298/800/BP

Source: Own elaboration.

At the next stage of the study, the parameters of analysed longwalls were monitored, which enabled to determine key parameters affecting shearer's productivity and gross work productivity indicator in an analysed group of collieries.

Table 2

Key technical parameters determining longwall shearers' productivity and work productivity in analysed longwalls

Id.	Longwall	Colliery	The time to reach a longwall [min]	Non-technological downtime coefficient [%]	Shearer's work time use in technological processes coefficient [%]	Average shearer's productivity [t/h]	Average daily number of productive shifts in a longwall [sh./d]	Average daily number of maintenance shifts in a longwall [sh./d]	The number of workers on a productive shift [workers/sh.]	The number of workers on a maintenance shift [workers/sh.]	Daily longwall gross coal output [Mg/d]
			T_d	W_{pp}	W_{wkpt}	$PrK_{śr}$	$LZPDR_o$	$LZKDR_o$	OZP_o	OZK_o	WDB_o
1	2	3	4	5	6	7	8	9	10	11	12
1.	Longwall A	Colliery X	85,0	34,4	56,8	399,2	3,90	0,50	30,9	32,5	3 570
2.	Longwall B	Colliery X	50,0	17,0	74,3	298,8	3,50	0,50	30,3	38,0	4 423
3.	Longwall C	Colliery X	85,0	34,2	75,3	287,1	3,50	0,50	34,0	39,0	3 414
4.	Longwall D	Colliery X	65,0	24,2	66,0	267,2	3,50	0,50	34,8	45,0	3 209
5.	Longwall E	Colliery Y	115,0	18,7	72,2	688,3	5,25	0,75	24,3	44,9	9 696
6.	Longwall F	Colliery Y	85,0	36,5	69,8	194,1	3,85	0,78	20,4	33,9	2 064
7.	Longwall G	Colliery Y	100,0	29,5	52,2	90,6	4,34	0,66	22,3	34,4	800

Source: Own elaboration.

Simulation calculations were undertaken with the work productivity analysis model[6], which takes into consideration work parameters of an analysed group of longwalls and collieries. To calculate work productivity, the model needed the following parameters characterising the employment level and structure in analysed collieries:

- employment level of underground workers: 4 586 workers in Colliery X and 3 437 workers in Colliery Y,
- employment level of surface workers: 741 workers in Colliery X and 646 workers in Colliery Y,
- total absence indicator of underground workers: 25,91% in Colliery X and 26,30% in Colliery Y,
- total absence indicator of surface workers: 22,03% in Colliery X and 24,43% in Colliery Y,
- the participation indicator of processing plant workers in colliery's surface employment: 58,67% in Colliery X and 58,71% in Colliery Y,
- the participation indicator of extraction processes service workers in colliery's underground employment: 13,46% in Colliery X and 17,26% in Colliery Y.

The simulation analysis was undertaken for 4 following calculation variants:

- variant I – without coal production on Saturdays and Sundays and without the reduction of a non-technological downtime indicator,
- variant II – without coal production on Saturdays and Sundays and the reduction of a non-technological downtime indicator,
- variant III – including coal production on Saturdays and Sundays and without the reduction of a non-technological downtime indicator,
- variant IV – including coal production on Saturdays and Sundays and the reduction of a non-technological downtime indicator.

In all variants, the analysis of possible technical and organizational changes was made aiming at the increase of a daily gross coal output in an analysed group of longwalls, and as a result the increase of shearer's effective work time. The base input data were determined as work parameters of longwalls, established during monitoring conducted in the period of one month.

In variant I, potential changes in the level of daily gross coal output derive from the increase of the number of productive shifts to the maximum possible number on working days. In this variant, other technical and organizational parameters remain unchanged.

[6] Gumiński A.: Model analizy wydajności pracy w kopalni węgla kamiennego i w grupie kopalń. Wydawnictwo Politechniki Śląskiej, Gliwice 2017.

In variant II, potential changes in the level of daily gross coal output derive from the increase of the number of productive shifts to the maximum possible number on working days and the reduction of non-technological downtime coefficient to 15%.

In variant III, potential changes in the level of daily gross coal output derive from the increase of the number of productive shifts to the maximum possible number on working days and on Saturdays and Sundays. In this variant, other technical and organizational parameters remain unchanged.

In variant IV, potential changes in the level of daily gross coal output derive from the increase of the number of productive shifts to the maximum possible number on working days and on Saturdays and Sundays, and the reduction of non-technological downtime coefficient to 15%.

As a result of the simulation calculations, for each variant, the following technical and organizational parameters for an analysed group of collieries were determined:

- daily gross coal output reserve,
- the number of productive shifts,
- daily gross coal output,
- the employment level change of productive workers,
- the employment level change of non-productive workers,
- gross work productivity indicator,
- the change of gross work productivity indicator.

To determine the daily coal output reserve for each of analysed longwalls, a calculation algorithm was worked out, consisting of the following 6 stages:

1. Stage – the calculation of effective work time of longwall's crew within one productive shift due to a formula as follows:

$$T_{ef} = 450 - T_d - T_p \tag{2}$$

where:

T_d – the time to reach a longwall [min],

T_p – the time to return from a longwall [min].

2. Stage – the calculation of maximal shearer's work time within a working day due to a formula as follows:

$$TPK_{dmax} = 1440 \cdot W_{wkpt} \cdot (1 - W_{pp}) \tag{3}$$

where:
W_{wkpt} – shearer's work time use in technological processes coefficient [%],
W_{pp} – non-technological downtime coefficient [%].

3. Stage – the calculation of maximal shearer's work time within a single productive shift due to a formula as follows:

$$TPK_{zmmax} = \frac{TPK_{dmax}}{LZPDR_o} \tag{4}$$

where:
$LZPDR_o$ – average daily number of productive shifts in a longwall [sh./d].

4. Stage – the calculation of maximal number of productive shifts on working days in a longwall $LZPDR_{max}$ to make use of the whole time of a working day due to a formula as follows:

$$LZPDR_{max} = \frac{1440 \cdot LZPDR_0}{T_{ef} \cdot LZKDR_0 \cdot (1 + LZPDR_0/LZKDR_0)} \tag{5}$$

where:
$LZKDR_o$ – average daily number of maintenance shifts in a longwall [sh./d].

5. Stage – the calculation of maximal daily gross coal output in a longwall due to a formula as follows:

$$WDB_{max} = WDB_{max\text{-}dr} + WDB_{max\text{-}sn} \cdot \frac{LDWP}{LD_r} \tag{6}$$

where:
LD_r – the number of working days in a year [d/y],
LDWP – the number of working weekends in a year [d/y];

a) for coal production on working days:

$$WDB_{max\text{-}dr} = LZPDR_{max} \cdot \frac{TPK_{zmmax}}{60} \cdot PrK_{śr} \tag{7}$$

b) for coal production on Saturdays and Sundays:

$$\text{if } LZPSN_{max} \geq 2 \cdot LZPDR_{max} \text{ then } LZPSN_{max} = 2 \cdot LZPDR_{max}$$

$$WDB_{max\text{-}sn} = LZPSN_{max} \cdot \frac{TPK_{zmmax}}{60} \cdot PrK_{śr} \tag{8}$$

where:

$WDB_{max\text{-}dr}$ – maximal daily gross coal output in a longwall on a working day [Mg/d],

$WDB_{max\text{-}sn}$ – maximal daily gross coal output in a longwall on Saturdays and Sundays [Mg/d],

$PrK_{śr}$ – average shearer's coal productivity [t/h],

$LZPSN_{max}$ – maximal number of productive shifts in a longwall on Saturdays and Sundays [sh./d].

6. Stage – the calculation of maximal daily gross coal output reserve in a longwall due to a formula as follows:

$$RW_{max} = WDB_{max} - WDB_0 \tag{9}$$

where:

RW_{max} – maximal daily gross coal output reserve in a longwall [Mg/d].

WDB_o – average daily gross coal output in a longwall [Mg/d].

After determining the maximum possible daily gross output in all longwalls, the gross work productivity indicator for a group of analysed collieries was calculated due to the following formula:

$$W = \frac{\sum_{i=1}^{m}\sum_{j=1}^{m_j} P_{b-ij}}{\sum_{i=1}^{m}\left[\sum_{j=1}^{m_i} \frac{OZP_{ij} \cdot LZP_{ij} + OZK_{ij} \cdot LZK_{ij}}{(1 - WA_{ij})} + Z_{pp-d-i} + Z_{pp-p-i}\right]} \tag{10}$$

where:

m – the number of collieries in an analysed group,

m_i – the number of longwalls in i-index colliery,

$P_{b\text{-}ij}$ – annual gross coal production in j-index longwall in i-index colliery [Mg/y],

OZP_{ij} – the number of workers in j-index longwall in i-index colliery on a productive shift [workers/sh.],

LZP_{ij} – the number of productive shifts in j-index longwall in i-index colliery,

OZK_{ij} – the number of workers in j-index longwall in i-index colliery on a maintenance shift [workers/sh.],

LZK_{ij} – the number of maintenance shifts in j-index longwall in i-index colliery,

WA_{ij} – total absence indicator of underground workers in j-index longwall in i-index colliery [%],

$Z_{pp\text{-}d\text{-}i}$ – the employment level of non-productive underground workers in i-index colliery [workers],

$Z_{pp\text{-}p\text{-}I}$ – the employment level of non-productive surface workers in i-index colliery [workers].

Table 3 summarizes the synthetic calculation results for all analysed variants.

Table 3

The result parameters of simulation calculation in a group of analysed collieries

Id.	Parameter	Unit	The initial state	Variant I	Variant II	Variant III	Variant IV
1.	Daily gross coal output reserve	[Mg/d]	0,0	3 195,0	4 674,0	14 524,0	16 554,0
2.	The number of productive shifts	[1/d]	27,8	31,6	31,6	43,4	43,4
3.	Daily gross coal output	[Mg/d]	27 176,0	30 371,0	31 850,0	41 700,0	43 730,0
4.	The employment level change of productive workers	[worker]	0,0	174,0	174,0	659,0	659,0
5.	The employment level change of non-productive workers	[worker]	0,0	0,0	0,0	690,0	690,0
6.	Gross work productivity indicator	[Mg/y/worker]	727,8	798,6	837,4	976,7	1 024,2
7.	The change of gross work productivity indicator	[Mg/y/worker]	0,0	70,8	109,6	248,9	296,4
8.	The percentage change of gross work productivity indicator	[%]	0,0	9,7	15,1	34,2	40,7

Source: Own elaboration.

As a result of the increase in daily gross coal output in a group of analysed longwalls, the following effects were achieved in the level of the gross work productivity indicators for an analysed group of collieries:

- in variant I, the increase of the gross work productivity indicator is 70,8 Mg/y/worker, to the level of 798.6 Mg/y/worker, i.e. by 9.7%,
- in variant II, the increase of the gross work productivity indicator is 109,6 Mg/y/worker, to the level of 837,4 Mg/y/worker, i.e. by 15,1%,
- in variant III, the increase of the gross work productivity indicator is 248,9 Mg/y/worker, to the level of 976,7 Mg/y/worker, i.e. by 34,2%,
- in variant IV, the increase of the gross work productivity indicator is 296,4 Mg/y/worker, to the level of 1 024,2 Mg/y/worker, i.e. by 40,7%.

4. Conclusions

The analysis enabled to determine a daily gross coal output reserve for an individual longwall and totally for a group of longwalls. Simulation calculations were made for organizational and technical changes focused on increasing shearer's effective work time. Simulation variants considered the possibility of coal production on Saturdays and Sundays and the reduction of non-technological downtimes.

The undertaken study of work productivity in a group of collieries enables the following conclusions:

1. The factors determining shearer's productivity in a longwall are crucial for achieving a high level of daily gross coal output, and thus determine the level of work productivity in a group of collieries. The appropriate level and structure of employment is also an important factor for a stable and efficient realisation of technological processes.
2. For an analysed group of longwalls in 2 collieries, the potential possibilities for improving the total gross work productivity indicator were determined based on a maximal gross coal output reserve in all analysed longwalls:
   - for a variant involving coal production on Saturdays and Sundays, the gross work productivity indicator level is 1 024.2 Mg/y/worker, i.e. the increase by 40.7% in relation to the initial state,
   - for a variant not involving coal production on Saturdays and Sundays, the gross work productivity indicator level is 837,4 Mg/y/worker, i.e. the increase by 15.1% in relation to the initial state,
3. The key aspect for the activity of coal companies is to increase work productivity through higher level of effective work time of longwall's shearer. To achieve that, the following actions should be undertaken:
   - more adequate employment level to realise effectively technological processes in longwalls,
   - further changes to minimize non-technological downtimes,
   - the increase of coal production on Saturdays and Sundays, maintaining a five-day working week for miners,
   - changes of transportation systems for miners to maximize work time of miners.

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